developer to invest time and effort in learning about the potential of the spectrum and also may require the developer to employ some staff for assistance.

Another source of uncertainty arises from the Commission. First, the grant of a license is not likely to be automatic. The entrepreneur may have to convince the Commission that its innovative spectrum use is in the public interest before the license is awarded. Second, the developer will not be certain about the terms of the license. If the terms are sufficiently onerous, the developer may simply decide that the use of the new spectrum is not a "business."

After the spectrum developer is awarded the license from the Commission, the developer will sink additional costs on equipment design, testing, and manufacturing associated with the possible offering of a new service. One would also expect the developer to have higher borrowing costs for a new, untried service than for more mature services.

To resolve demand uncertainties, the developer may sink additional costs in market research surveys. The developer will also likely have to convince potential customers to "test" the new service with promotional rates. The developer will construct a strategy to convince would-be customers that both the service and the entrepreneur are credible. Most of these costs are likely to be incurred after the award of the license.

As the scope of these uncertainties is narrowed, there are two possible outcomes. First, the developer may decide that the initial intuition was wrong and that the spectrum in fact cannot be used profitably and the spectrum will ultimately revert back to the stewardship of the Commission. As a result, all of the sunk costs expended by the developer will not be recovered, a possibility that the entrepreneur knew at the time of the sunk cost investment and was accounted for by the entrepreneur in his/her decision to make that investment.

Second, the developer may find that its intuition was correct, the business will be profitable, and (after incurring start-up losses) the developer will begin recovering the sunk costs.

The success of the developer can be expected to breed imitators. There will be some imitators who expect relatively immediate profits from entry. They will apply for the licenses and (at this early stage) are likely to incur costs to convince customers that the service is desirable. Other imitators will believe that waiting is more profitable. They will apply for licenses and hold them for either future use (when the necessary expenditure of sunk costs has been considerably reduced) or for resale as the success of the service becomes more apparent.

Both groups of imitators can be viewed as "free-riding" on the efforts of the original spectrum developer. No imitator will have to expend the kinds of costs that were expended by the original developer. For example, those prospective licensees coming "second" will not likely have to expend as much effort as the spectrum developer to convince the Commission that the spectrum can be used for a new and desirable service. The problem confronted by the spectrum developer is to recover the sunk costs before the imitation becomes too widespread.

Based upon the discussion in the *Notice*, it appears to have been at this imitation stage that the Commission decided to propose an auction of the 39 GHz portion of this band and the reclamation of the licenses of "irresponsible" licensees. Specifically, the Commission notes that "there has been a substantial and growing number of applications to use the 39 GHz band..."[95]

The apparent inference by the Commission—that the surge in applications signaled the value of that spectrum—is surely correct. The auctioning of unlicensed spectrum would not likely have any adverse consumer consequences and would permit the Commission to collect some of the profits due to its stewardship. It is the possibility that the Commission will reclaim the spectrum already licensed that gives rise to consumer costs without offsetting benefits.[96]

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[95] *Notice*, ¶7.

[96] To be clear, this discussion does not address whether the Commission has the authority to reclaim the spectrum. Assuming the Commission claims such authority, the question is whether the Commission as a matter of policy should reclaim the spectrum.

2. *Short-Run Effects on Consumers of Spectrum Reclamation*

In the short run, the possibility that some or many of the licenses of existing licensees will be reclaimed will discourage the growth of the service. Prospective purchasers of the new service will be reluctant to invest the time, effort, and funds to learn about the new services and, importantly, about the specific suppliers that use the 39 GHz spectrum. These potential customers will be concerned that the identity of specific supplier identities and offerings could change as a result of reclamation and that, after reclamation, the incumbent licensees may not be able to re-acquire their reclaimed licenses in the auction. Alternatively, the purchaser may be willing to incur these supplier-specific costs and begin service, but only at a substantially reduced price for the service.[97]

There is little doubt that the reclamation threat will prevent prices for the services currently provided by the incumbent licenses from falling as far as they otherwise would, although the magnitude of this effect is difficult to quantify. However, even a relatively small effect on prices can generate significant consumer costs. As an illustration, suppose that in the absence of the reclamation threat, actual and prospective competition between 37-40 GHz incumbents, CAPs, and LECs would reduce access prices by an additional one-tenth of one percentage point. Such a reduction in access costs would generate savings of over $30 million per year.

Of course, for some individual users, the costs of the reclamation threat would be more substantial. For example, the only economic way to link a business complex with a relatively low volume of voice and data traffic may be through "Wireless Fiber."™. If, as a result of the reclamation threat, this complex is reluctant to use the 39 GHz incumbent, the access costs for this complex may substantially increase.

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[97] In addition, until these uncertainties are resolved, current customers may delay expanding their purchases, and capital costs for incumbents may increase.

3. *Longer-Run Effects of Reclamation on Efficient Use of Spectrum*

Even if the Commission could render its reclamation decisions immediately—thereby eliminating any interim uncertainty, the longer-run effects of reclamation are likely to be substantial. If the original spectrum developer is forced to bid on the reclaimed spectrum, it will base its bid on the expected future profits from using the spectrum. What is relevant for this calculation is future revenues and future costs, not past costs. As a result, the developer may not be able to recover the initial spectrum development costs.

For example, the spectrum developer may have incurred $1000 in sunk costs. In the future, it anticipates revenues of (say) $1500 and costs of $400, or future net revenues of $1100. Absent reclamation, the developer would have recovered its sunk costs, plus earned a normal risk-adjusted return (in this case, $100) on its initial, sunk investment.

By the time the auction is held on the reclaimed spectrum, the efforts of the spectrum developer (and perhaps those of some of the other incumbent licensees) in narrowing the scope of demand and cost uncertainty may have become well-known (if not completely known) to other prospective bidders. On the basis of the experience of the developer and the early imitators, prospective bidders might estimate future revenues of $1400 and future costs of $700. Thus, these prospective bidders for the reclaimed spectrum would be willing to bid as much as $700 for the licenses. The spectrum developer can clearly outbid its competitors for what was once its license because the future value to it is $1100. As long as the developer bids something just over $700, it will regain the spectrum that was reclaimed by the Commission. However, the developer will now be able to recover something less than $400 of its sunk costs. Thus, the developer will have lost more than $600 plus any return on its investment.[98] Had it known at the very outset that the Commission would reclaim its spectrum, the developer would never have

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[98] The reacquisition of the spectrum by the developer is its most profitable strategy. If the developer bid anything less than the second-highest bidder, it would not re-acquire the license and would not recover any of its sunk costs of $1000.

incurred the expenditures to develop the spectrum because reclamation would make recovering its sunk costs impossible.

An analogy might be drawn to a real estate developer who believes that some lakefront property can be developed into homes that are valued by consumers and would yield the developer a substantial return. To this end, the developer purchases the property at a price reflecting the value of the (undeveloped) property to the property owners, but not reflecting the increased value of the developed property. If the developer believed that, after having developed the property, the local government would require that the property be returned to the original owners, the developer would not have made the investments necessary to realize the full value of the property.

Unless the current and future uses of 37-40 GHz spectrum do not require any additional marketing or production innovation whose value could be "expropriated" by yet another auction or unless the Commission could somehow commit not to "re-auction" the spectrum if it became apparent that the band was more valuable than believed at the time of the auction, reclamation will have additional adverse impacts on the use of this band. Specifically, the reclamation will discourage licensees from investing in innovative ways of using or marketing that spectrum. The risk is that, having rendered the spectrum more valuable, the Commission will reclaim the spectrum for auction and the innovating licensee will not recover the sunk costs of the innovation.

Even if either of the two premises were correct for the 39 GHz band, the adverse future consequences for consumers are likely to be substantial if the Commission proceeds with reclamation. The possibility that the Commission may again reclaim other spectrum that it has "given away" once that spectrum has been developed and its value increased will discourage prospective spectrum developers from incurring the costs and attendant risks required for innovation. As a result, the incentive to be the "first" with a new method of exploiting spectrum will be reduced because of the possibility of after-the-fact spectrum reclamation by the

Commission. Creating the incentive to be "second" rather than first with an innovation likely will cause some spectrum resources not to be fully exploited or to remain fallow. Consequently, some (perhaps many) end-users will rely on higher-cost alternatives or forego some new services that would otherwise have been provided.

Moreover, the reclamation of 39 GHz spectrum may significantly raise the risk, as perceived by current and prospective licensees, that the Commission is prepared to substantially change the "rules of the game" after the game has started. In future auctions, bidders will be aware of this increased possibility and will reduce the amount they are willing to pay for spectrum rights. As a result, the revenues from future auctions will be less than would otherwise be the case.

4. *Policy Implications I: The Net Benefits of Reclamation*

In weighing the costs and benefits of its proposal to reclaim and auction currently licensed spectrum, the Commission should carefully consider the following four factors. First, the reclamation will not result in a superior allocation of spectrum resources. As noted in the previous section, regardless of how and to whom the licenses are initially assigned, the Commission can rely on market forces to allocate the spectrum resources to its most highly-valued uses. Second, the short-run effects of the proposed spectrum reclamation will reduce both the current demand and the supply of services using the 39 GHz portion of this band. As a result, end-users will rely on less efficient or more costly alternatives for access and transport. Third, in the longer run, the reclamation may reduce the incentives of current and prospective licensees to develop new uses for licensed spectrum and for fallow spectrum. Fourth, by increasing the possibility of future after-the-fact reclamation, the moneys the Commission might earn from future auctions will be reduced.

5. *Policy Implications II: Identifying "Responsible Licensees"*

If the Commission nonetheless decides to proceed with reclamation, it can reduce the costs to consumers of the process if it limits the class of licensees that may be subject to

reclamation. Choosing any criterion for identifying which incumbent 39 GHz licensees are "responsible" is an unenviable task. The Commission's proposed criterion, however — identifying "responsible" licensees by a count of the number of operational links in each licensed area — is far too narrow a basis for making the distinction.

If a "responsible" licensee is one who appears committed to using the spectrum (rather than holding it for later resale), the appropriate conceptual test would be evidence that the licensee has incurred "significant" sunk costs in utilizing the spectrum. Using this criterion also would help minimize the cost to consumers of reclamation. However, the correlation of operational links with the extent of a sunk cost commitment to a new service is likely to be so low that the Commission will reclaim the spectrum of some licensees who in fact are "responsible" and have committed substantial investments in providing service.

The strategy adopted by WinStar suggests how low the correlation between sunk costs and operational links might be. As the first to recognize the value of the 37-40 GHz spectrum, WinStar expended considerable funds and "sweat equity" to determine whether the offering of "Wireless Fiber"™ services was economically and technically feasible. In addition, the flexibility afforded by the then-existing licensing requirements permitted WinStar to adopt a marketing strategy that did not have to be predicated on immediate buildouts of its licensed areas. Instead, WinStar focused its resources on setting the stage for the geographically widespread offering of diverse "Wireless Fiber"™ services.

Part of this strategy was and is to establish WinStar as a credible supplier and "Wireless Fiber"™ as a credible service. To this end, WinStar has expended considerable effort to hire personnel with recognized experience in telephony and to disseminate that information to industry participants. Similarly, it has concentrated on convincing large, well-known firms (such as MCI) to use WinStar's services, thereby enhancing its credibility with other would-be customers. Among others, one reason why this particular task has been difficult is because end-users have come to believe that fiber transport has been proven superior to microwave

transmission. In establishing as customers large, established firms — a time consuming process — WinStar (and its imitators) will find it easier to dispel these beliefs.

WinStar also has sunk investments in seeking state regulatory authority to offer service. To enable it to market itself as a nationwide provider of "Wireless Fiber"™ services, WinStar has sought and received from 21 states the necessary regulatory authority to offer intrastate CAP-like service, and has applications pending in another 7 states. WinStar also has sought and received state authority to offer competitive local exchange (CLEC) service in 5 states with applications pending in another 5 states.[99]

Thus, WinStar—and perhaps other incumbent licensees—have focused more on preparation rather than operation as the most likely route to ultimate profitability. By their very nature, the sunk costs incurred by WinStar in implementing this strategy will not have a high correlation with the number of operational links. Indeed, given the strategy adopted by WinStar, it would have been inefficient to install equipment at an early stage of business development—as would be required by the Commission's newly proposed buildout requirements—and have it remain idle.

This discussion indicates that in distinguishing between "responsible" licensees and other licensees, the Commission in principle should choose a characteristic that is more highly correlated with the expenditure of sunk costs than the number of operational links. The Commission should consider an approach that is less likely to incorrectly classify "responsible" licensees as "other" licensees.[100] For example, the Commission could accept other evidence of

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[99] The recently passed Telecommunications Act of 1996 changes the authority of the states to limit authorization of various types of local service and the authorization that is needed. This change in the rules does not alter the fact that WinStar's past investments, under the then existing rules, are evidence of its commitment to use its licenses.

[100] It seems reasonable to presume that the losses from mistakenly classifying "responsible" licensees as "other" would be larger than the losses from classifying "other" licensees as "responsible." The Commission's errors will deter both sets of licensees from incurring expenditures to deploy fallow spectrum. But it is the "responsible" licensees whose entrepreneurial instincts led them to believe that the fallow 39 GHz spectrum could be efficiently deployed in the first place. In technical terms, the loss function is likely to be asymmetric.

incumbent "responsibility," such as the number of full-time employees, leases for office space, and applications to state PUCs for the necessary regulatory authority to offer service. If the Commission continues to rely on the number of operational links as its criterion, the Commission should consider a less stringent threshold, such as the alternative proposal in the *Notice* to vary the required number of operational links by market size.

IV. Summary of Conclusions

Our conclusions are straightforward. First, the stringency of the Commission's 600 MHz cap is not necessary to maintain acceptable competitive market performance in the supply of 37-40 GHz spectrum. Our analysis indicates that the relevant product market is likely to be considerably broader than the 37-40 GHz band and likely includes services provided by fiber optic cable, twisted-pair cable, and coaxial cable as well as other spectrum-based service. As a result, this is a market that will be dominated by the LECs for some time to come. If a single licensee were to acquire all of the 37-40 GHz spectrum because of the absence of a spectrum cap, that licensee still would have little if any effect on price in the LEC-dominated market. Even if the product market is defined more narrowly to consist only of spectrum alternatives to the 37-40 GHz band, the Commission can permit one licensee to control considerably more spectrum than the proposed 600 MHz without raising anticompetitive concerns.

In brief, our analysis suggests that competition among spectrum suppliers will be vibrant, even with very lenient spectrum caps. This assurance of competitive behavior should permit the Commission to provide prospective licensees with maximum flexibility in choosing how much of the 37-40 GHz spectrum to acquire. Given the early stages of development of the millimeter wave bands, such a policy will allow market forces—the rivalry among different spectrum providers to find ways of satisfying end-user demands most efficiently— rather than regulatory prescription to shape this nascent industry in a way that best serves consumers.

This same competition also provides the Commission with assurance that the 37-40 GHz spectrum will be used in the most efficient manner to satisfy end-user demands. Consequently, the Commission need not and should not impose on licensees a host of detailed engineering, use, and buildout requirements.

Adoption of the Commission's proposal to reclaim some or much of the spectrum of the incumbent licensees in the 39 GHz portion of the 37-40 GHz band will likely generate substantial consumer harm. Spectrum reclamation and the subsequent auction of that spectrum will do nothing to guide spectrum to higher-valued uses. The incumbent licensees already have the incentive to find the most profitable way of using this spectrum. However, reclamation is likely to delay the growth of these spectrum-based services in the short run as end-users await the outcome of the Commission's reclamation decision and the subsequent auction. In the longer run, spectrum reclamation can only reduce the incentives of entrepreneurs to find innovative ways of using fallow or underutilized spectrum.

If the Commission nonetheless adopts its reclamation proposal, the Commission should use very lenient criteria to distinguish "responsible" licensees from others. By so doing, the Commission will reduce the chances of mistakenly classifying a "responsible" licensee as one of the "other" licensees. In this way, the Commission can reduce the short- and longer-run costs associated with spectrum reclamation. The Commission's proposal to use the number of operational links as the basis for its reclamation decisions will likely result in this kind of costly mistake.

Table 1

HHI Calculations

Product Market Includes: 37 - 40 GHz, 18 GHz, 23 GHz, 28 GHz, and Above 40 GHz

37 - 40 GHz Cap: 600 MHz

Product Market	Band Width (MHz)	Market Share	HHI Contribution
37 - 40 GHz			
Licensee A	600	7.69%	59.17
Licensee B	600	7.69%	59.17
Licensee C	600	7.69%	59.17
Licensee D	600	7.69%	59.17
Licensee E	400	5.13%	26.30
Subtotal	2800	-	
17.7 - 19.7 GHz			
Licensee A	100	1.28%	1.64
Licensee B	100	1.28%	1.64
Licensee C	100	1.28%	1.64
Licensee D	100	1.28%	1.64
Licensee E	100	1.28%	1.64
Licensee F	100	1.28%	1.64
Licensee G	100	1.28%	1.64
Licensee H	100	1.28%	1.64
Subtotal	800		
21.2 - 23.6 GHz			
Licensee A	100	1.28%	1.64
Licensee B	100	1.28%	1.64
Licensee C	100	1.28%	1.64
Licensee D	100	1.28%	1.64
Licensee E	100	1.28%	1.64
Licensee F	100	1.28%	1.64
Licensee G	100	1.28%	1.64
Licensee H	100	1.28%	1.64
Licensee I	100	1.28%	1.64
Licensee J	100	1.28%	1.64
Subtotal	1000		
28 GHz Band			
Licensee	400	5.13%	26.30
40.5 - 42.5, 47.4 - 48.2 GHz			
Licensee A	600	7.69%	59.17
Licensee B	600	7.69%	59.17
Licensee C	600	7.69%	59.17
Licensee D	600	7.69%	59.17
Licensee E	400	5.13%	26.30
Subtotal	2800		
TOTALS	**7800**	**100.00%**	**551.86**

Source: CRA calculations.

Table 2

HHI Calculations

Product Market Includes: 37 - 40 GHz, 18 GHz, 23 GHz, 28 GHz, and Above 40 GHz

37 - 40 GHz Cap: 1400 MHz

Product Market	Band Width (MHz)	Market Share	HHI Contribution
37 - 40 GHz			
Licensee A	1400	17.95%	322.16
Licensee B	1400	17.95%	322.16
Subtotal	2800		
17.7 - 19.7 GHz			
Licensee A	100	1.28%	1.64
Licensee B	100	1.28%	1.64
Licensee C	100	1.28%	1.64
Licensee D	100	1.28%	1.64
Licensee E	100	1.28%	1.64
Licensee F	100	1.28%	1.64
Licensee G	100	1.28%	1.64
Licensee H	100	1.28%	1.64
Subtotal	800		
21.2 - 23.6 GHz			
Licensee A	100	1.28%	1.64
Licensee B	100	1.28%	1.64
Licensee C	100	1.28%	1.64
Licensee D	100	1.28%	1.64
Licensee E	100	1.28%	1.64
Licensee F	100	1.28%	1.64
Licensee G	100	1.28%	1.64
Licensee H	100	1.28%	1.64
Licensee I	100	1.28%	1.64
Licensee J	100	1.28%	1.64
Subtotal	1000		
28 GHz Band			
Licensee	400	5.13%	26.30
40.5 - 42.5, 47.4 - 48.2 GHz			
Licensee A	1400	17.95%	322.16
Licensee B	1400	17.95%	322.16
Subtotal	2800		
TOTALS	**7800**	**100.00%**	**1344.51**

Source: CRA calculations.

Table 3

HHI Calculations

Product Market Includes: 37 - 40 GHz, 18 GHz, 23 GHz, 28 GHz, and Above 40 GHz

37 - 40 GHz Cap: 1400 MHz

Product Market	Band Width (MHz)	Market Share	HHI Contribution
37 - 40 GHz			
Licensee A	1400	17.95%	322.16
Licensee B	700	8.97%	80.54
Licensee C	300	3.85%	14.79
Licensee D	200	2.56%	6.57
Licensee E	200	2.56%	6.57
Subtotal	2800		
17.7 - 19.7 GHz			
Licensee A	100	1.28%	1.64
Licensee B	100	1.28%	1.64
Licensee C	100	1.28%	1.64
Licensee D	100	1.28%	1.64
Licensee E	100	1.28%	1.64
Licensee F	100	1.28%	1.64
Licensee G	100	1.28%	1.64
Licensee H	100	1.28%	1.64
Subtotal	800		
21.2 - 23.6 GHz			
Licensee A	100	1.28%	1.64
Licensee B	100	1.28%	1.64
Licensee C	100	1.28%	1.64
Licensee D	100	1.28%	1.64
Licensee E	100	1.28%	1.64
Licensee F	100	1.28%	1.64
Licensee G	100	1.28%	1.64
Licensee H	100	1.28%	1.64
Licensee I	100	1.28%	1.64
Licensee J	100	1.28%	1.64
Subtotal	1000		
28 GHz Band			
Licensee	400	5.13%	26.30
40.5 - 42.5, 47.4 - 48.2 GHz			
Licensee A	1400	17.95%	322.16
Licensee B	700	8.97%	80.54
Licensee C	300	3.85%	14.79
Licensee D	200	2.56%	6.57
Licensee E	200	2.56%	6.57
Subtotal	2800		
TOTALS	**7800**	**100.00%**	**917.16**

Source: CRA calculations.

Table 4

HHI Calculations

Product Market Includes: 37 - 40 GHz, 18 GHz, 23 GHz, and 28 GHz

37 - 40 GHz Cap: 600 MHz

Product Market	Band Width (MHz)	Market Share	HHI Contribution
37 - 40 GHz			
Licensee A	600	12.00%	144.00
Licensee B	600	12.00%	144.00
Licensee C	600	12.00%	144.00
Licensee D	600	12.00%	144.00
Licensee E	400	8.00%	64.00
Subtotal	2800		
17.7 - 19.7 GHz			
Licensee A	100	2.00%	4.00
Licensee B	100	2.00%	4.00
Licensee C	100	2.00%	4.00
Licensee D	100	2.00%	4.00
Licensee E	100	2.00%	4.00
Licensee F	100	2.00%	4.00
Licensee G	100	2.00%	4.00
Licensee H	100	2.00%	4.00
Subtotal	800		
21.2 - 23.6 GHz			
Licensee A	100	2.00%	4.00
Licensee B	100	2.00%	4.00
Licensee C	100	2.00%	4.00
Licensee D	100	2.00%	4.00
Licensee E	100	2.00%	4.00
Licensee F	100	2.00%	4.00
Licensee G	100	2.00%	4.00
Licensee H	100	2.00%	4.00
Licensee I	100	2.00%	4.00
Licensee J	100	2.00%	4.00
Subtotal	1000		
28 GHz Band			
Licensee	400	8.00%	64.00
TOTALS	**5000**	**100.00%**	**776.00**

Source: CRA calculations.

Table 5

HHI Calculations

Product Market Includes: 37 - 40 GHz, 18 GHz, 23 GHz, and 28 GHz

37 - 40 GHz Cap: 1400 MHz

Product Market	Band Width (MHz)	Market Share	HHI Contribution
37 - 40 GHz			
Licensee A	1400	28.00%	784.00
Licensee B	1400	28.00%	784.00
Subtotal	2800		
17.7 - 19.7 GHz			
Licensee A	100	2.00%	4.00
Licensee B	100	2.00%	4.00
Licensee C	100	2.00%	4.00
Licensee D	100	2.00%	4.00
Licensee E	100	2.00%	4.00
Licensee F	100	2.00%	4.00
Licensee G	100	2.00%	4.00
Licensee H	100	2.00%	4.00
Subtotal	800		
21.2 - 23.6 GHz			
Licensee A	100	2.00%	4.00
Licensee B	100	2.00%	4.00
Licensee C	100	2.00%	4.00
Licensee D	100	2.00%	4.00
Licensee E	100	2.00%	4.00
Licensee F	100	2.00%	4.00
Licensee G	100	2.00%	4.00
Licensee H	100	2.00%	4.00
Licensee I	100	2.00%	4.00
Licensee J	100	2.00%	4.00
Subtotal	1000		
28 GHz Band			
Licensee	400	8.00%	64.00
TOTALS	**5000**	**100.00%**	**1764.00**

Source: CRA calculations.

Table 6

HHI Calculations

Product Market Includes: 37 - 40 GHz, 28 GHz, and Above 40 GHz

37 - 40 GHz Cap: 800 MHz

Product Market	Band Width (MHz)	Market Share	HHI Contribution
37 - 40 GHz			
Licensee A	600	10.00%	100.00
Licensee B	600	10.00%	100.00
Licensee C	600	10.00%	100.00
Licensee D	600	10.00%	100.00
Licensee E	400	6.67%	44.44
Subtotal	2800		
28 GHz Band			
Licensee	400	6.67%	44.44
40.5 - 42.5, 47.4 - 48.2 GHz			
Licensee A	600	10.00%	100.00
Licensee B	600	10.00%	100.00
Licensee C	600	10.00%	100.00
Licensee D	600	10.00%	100.00
Licensee E	400	6.67%	44.44
Subtotal	2800		
TOTALS	**6000**	**100.00%**	**933.33**

Source: CRA calculations.

Table 7

HHI Calculations

Product Market Includes: 37 - 40 GHz, 28 GHz, and Above 40 GHz

37 - 40 GHz Cap: 1000 MHz

Product Market	Band Width (MHz)	Market Share	HHI Contribution
37 - 40 GHz			
Licensee A	1000	19.23%	369.82
Licensee B	1000	19.23%	369.82
Subtotal	2000		
28 GHz Band			
Licensee	400	7.69%	59.17
40.5 - 42.5, 47.4 - 48.2 GHz			
Licensee A	1000	19.23%	369.82
Licensee B	1000	19.23%	369.82
Licensee C	800	15.38%	236.69
Subtotal	2800		
TOTALS	**5200**	**100.00%**	**1775.15**

Source: CRA calculations.

Technical and Economic Considerations in the Allocations of Radio Spectrum at 37-40 GHz: Lessons from the DEMS/DTS Technical Rules

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Technical and Economic Considerations in the Allocations of Radio Spectrum at 37 GHz: Lessons from the DEMS/DTS Technical Rules

I. Introduction

In ET Docket No. 95-183[1], the Federal Communications Commission ("FCC" or "the Commission") has undertaken an important proceeding that may have significant impact on the development of competition in the provision of local telecommunications services and on the efficiency with which the associated spectrum in the frequency range from 37.0 to 40.0 GHz is utilized. The purpose of this paper is to review certain technical and economic aspects of the proposed rules to govern the systems that will evolve in this frequency range. The balance of the paper is divided into four parts. Section II provides some basic background and analysis of a key issue underlying the proceeding -- namely, are government imposed spectral efficiency and related standards necessary in services where exclusive use of spectrum is involved -- while Section III analyzes in general terms the particular measure of spectral efficiency discussed by the Commission in the Notice. Section IV examines the proposed rules in light of earlier experience with the DEMS/DTS Technical Rules and Section V identifies and analyzes issues that would arise if government/non-government sharing of the spectrum is permitted. Finally, Section VI summarizes our analyses and the conclusions we reach.

II. The Role of Spectral Efficiency and Related Standards

Broadly speaking, spectral efficiency can be defined as the amount of information that can be transferred in a given amount of time in a given amount of spectrum over a given geographic area.[2] Spectral efficiency is an important concept because the radio spectrum resource is scarce and has significant economic value, especially in major urban areas. Accordingly, it is important that the Commission adopt policies and rules that create incentives for its efficient use. There are two ways of promoting efficiency. The first is for the Commission to establish standards for spectral efficiency and related characteristics much as the government did in establishing fuel efficiency requirements for automobiles as a result of the oil crisis in the mid-1970s. The second is for the Commission to create economic incentives to encourage the efficient use of the resource. This can be accomplished by granting "quasi-property rights."

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[1] Notice of Proposed Rulemaking and Order In the Matter of Amendment of the Commission's Rules Regarding the 37.0-38.6 GHz and 38.6-40.0 GHz Bands, ET Docket No. 95-183 and Implementation of Section 309(j) of the Communications Act -- Competitive Bidding, PP Docket No. 93-253, FCC 95-500, Released December 15, 1995 ("the Notice").

[2] The concept of spectral efficiency is discussed in more detail in Section II.

In certain situations, e.g., the traditional private land mobile radio services in some bands, the Commission does not issue licenses that give the operator exclusive use of a channel or other amount of spectrum in a geographic area. In other words, the spectrum is shared among several users in an area. In such situations, there is little incentive for an individual licensee to adopt a more spectrally efficient technology because he or she does not capture the economic benefits of doing so.[3] A simple example of this is where a licensee might voluntarily reduce the power of a base station to minimize interference to other co-channel users. Since reducing power reduces the performance of the licensee's system while conveying the resulting benefits to other, unaffiliated, users sharing the channel, their is little or no incentive for the licensee to do so.

In situations where quasi-property rights have not been created (i.e., where the licensees do not have exclusive use of spectrum in a given geographic area), government action in the form of minimum spectral efficiency standards is clearly needed. However, as the discussion in Section III below establishes, properly defining spectral efficiency standards is difficult from a technical standpoint and, once defined, specifying the exact level of spectral efficiency to be employed, enforcing that level of spectral efficiency, and adjusting the specified level of spectral efficiency over time to reflect changing economic conditions is problematical at best. Where a system of quasi-property rights has been established, there is no need to establish minimum spectral efficiency standards or related requirements for frequency tolerance, emission masks, adjacent channel interference, or antenna characteristics when the interference produced is internal to the licensee's system. Consequently, except in those situations where the benefits of sharing out-weigh other considerations, this Nation's traditional reliance upon property rights and economic forces is clearly the preferred solution.[4]

The preferability of relying upon quasi-property rights and economic forces is clearly demonstrated in the Commercial Mobile Radio Services. For example, in the Cellular Mobile Radio Service, after the Commission allocated and assigned the spectrum on an exclusive basis and made certain basic technical decisions with the aid of the industry, it allowed licensees a great

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[3] In the economic literature, this is often referred to as the "tragedy of commons." It has arisen lately in fishing in international waters where, in the absence of property rights, individual fishermen have little or no incentive to voluntarily limit their fishing to maximize the yield of the fishing grounds over time. This is because such a voluntary action would simply lead to others expanding their catch in the short term. With private ownership (and government protection of those property rights) the fishermen would have the incentive to manage the resource in a such a way that the yield of the resource is maximized rather than depleted through over fishing.

[4] An example of a situation where the benefits of sharing spectrum on a non-exclusive basis is paramount is in the use of Part 15 equipment on an unlicensed basis. The cost of licensing the use of such equipment (e.g., a low power wireless microphone) could eliminate the sale and utilization of the devices entirely.

deal of technical flexibility in how the channels created were used. Consequently, with the rapid growth in the service, the cellular licensees, especially those serving major urban areas where congestion is a particular problem, have adopted a whole range of different technological strategies to increase the efficiency with which they use their channels.[5] The benefits from going to more spectrally efficient technology include not only a significant expansion of capacity but also a reduction in the costs of the infrastructure produced by spreading fixed costs (e.g., certain cell site costs) over more subscribers. Because they capture the benefits of adopting the more spectrally efficient technology, they have the incentive to use the spectrum more efficiently without government prescribed efficiency standards.[6]

Likewise, many Specialized Mobile Radio ("SMR") operators are rebuilding their systems to employ more spectrally efficient Time Division Multiple Access technology as well as employ frequency reuse, and radio paging companies, working with their equipment providers, have continuously increased the data rates (and hence capacity) of their channels. In addition, increased frequency reuse is being implemented by some paging companies to further increase spectral efficiency and system capacity. This has all occurred without the government mandating such changes through spectral efficiency requirements. In short, by establishing a system of quasi-property rights and a competitive environment in CMRS, the Commission has created strong incentives for the efficient use of the spectrum and thereby largely eliminated the need for government mandated spectral efficiency and related standards.

In the Notice, the Commission is proposing to award licenses in the 37.0 - 40.0 GHz band on an exclusive use, rather than a shared use, basis and thus the licensees will have exactly the same incentives that CMRS providers have had to evolve their systems in a spectrally efficient manner. Thus, other than establishing technical rules to protect other radio systems/services, we conclude that there is no need for the Commission to establish minimum standards of spectral efficiency or requirements for frequency tolerance, emission masks, adjacent channel interference, or antenna characteristics. Indeed, as described in more detail below, any attempt to specify such

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[5] These technological choices include the adoption of narrower-band analog technology (e.g., N-AMPS), the use of TDMA (e.g., IS-54/IS-136) and the use of CDMA (IS-95). According to a contact at MTA-EMCI, at the end of 1995 there were 33.7 million total cellular subscribers with from 0.7 to 1.0 million of these subscribers having digital service. All commercial digital cellular systems presently use TDMA; however, about half of the cellular operators plan on using CDMA when it becomes available. AT&T presently has about 80 percent of the digital cellular subscribers. There were no digital cellular subscribers prior to 1993.

[6] The Commission has long recognized the benefits of exclusive use of frequencies to encourage spectral efficiency. See, for example, In the Matter of Spectrum Efficiency in the Private Land Mobile Radio Bands in Use Prior to 1968, 6 FCC Rcd 4126, 4133 (1991) and 10 FCC Rcd 10076, 10129-10130 (1995).

standards and requirements could seriously distort technology choices, raise costs unnecessarily, and, as demonstrated with the earlier experience with the DEMS/DTS, have significant negative impact on the viability of operators in this frequency range and, consequently, on their ability to provide meaningful competition to the entrenched local exchange carriers.

III. Analysis of Spectral Efficiency and Related Measures Proposed by the Commission

In the Notice, the Commission is considering establishing spectral efficiency and related standards for operations in the 37.0 - 40.0 GHz band. One such standard is a requirement for one bit per second per hertz ("bps/Hz") modulation efficiency. Not only is such a standard unnecessary for the reasons described above, it can significantly distort technology choices and needlessly raise costs. There are many reasons that a spectral efficiency standard based only upon modulation efficiency can lead to suboptimal results. As noted earlier, spectral efficiency can be defined as the amount of information that can be transferred in a given amount of time in a given amount of spectrum over a given geographic area. Considering only modulation efficiency and not better geographic frequency reuse and coding improvements, for example, can lead to less than optimal technological choices. For instance, a standard tradeoff available to the communication system engineer is to move to a less efficient but more robust modulation technique in order to gain additional protection against interference.[7] The additional protection against interference means, in turn, that the same frequencies or channels can be reused at closer distances within, say, a metropolitan area. The result may well be the ability to transfer a much greater total amount of information per hertz in the geographic area, i.e., more information per hertz per square mile. To use a hypothetical example, going from 1 bps/Hz to .5 bps/Hz might cut the required reuse distance in half thus quadrupling the amount of frequency reuse that could be obtained.[8] Thus, in this hypothetical example, a minimum modulation efficiency of 1 bps/Hz would actually cut spectral efficiency in half compared with what could be obtained with the lower, .5 bps/Hz requirement.

Similarly, through a technique known as channel coding, the communications engineer can add redundant bits to a data stream to allow the use of more robust error correcting techniques and, consequently, reduce the required signal-to-interference ratio required for an acceptable error rate. Thus, the engineer could increase the speed of transmission (i.e., the bit rate) in order to meet an artificially imposed modulation efficiency requirement while *reducing* the actual rate at which information is being transferred. This would be done by utilizing the extra bits for redundancy rather that to convey additional information in a given amount of time. Thus, a

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[7] In other words, the system would operate at an acceptable bit error rate at a lower signal to interference ratio.

[8] This is an illustrative example only, the exact tradeoff between modulation efficiency and frequency reuse depends on many other system design choices, and the operating environment.

higher modulation efficiency does not necessarily mean that more information will be transferred per hertz per square mile.[9] Another technique available to the communication engineer is source coding. With source coding, redundant information is removed from the signal being transmitted thus decreasing the required signaling rate over the channel. Taken by itself, this would appear to make additional channel capacity available for conveying other information. However, the removal of source redundancy makes the successful transmission of the desired information more sensitive to channel-induced errors. This, in turn, could increase the frequency reuse distance to compensate for greater sensitivity to errors and, depending upon a number of tradeoffs, this may nor may not result in increased spectral efficiency as measured by the amount of information transferred per hertz per square mile.

Likewise, a communications engineer has a host of tradeoffs involving antennas. For example, the engineer might choose a more robust, but less efficient (in terms of bits per second per hertz), modulation technique that would allow the same spectrum to be reused in adjacent beams of a sectorized antenna.[10] With arbitrarily specified antenna characteristics, the systems engineer may not be able to make the optimal tradeoff between modulation efficiency/robustness and the number of sectors. Finally, it might be more efficient for the engineer to meet adjacent channel interference requirements by reducing transmitter power only on those channels that are next to other channels used by other systems rather than to deploy equipment with a stringent emission mask. Thus, we conclude, as indicated above, that improperly chosen spectral efficiency and related standards can significantly distort technology choices and needlessly raise costs.[11]

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[9] The tradeoff between coding and modulation efficiency is becoming increasingly important as engineers develop an integrated system approach rather than optimizing each of the two factors individually. Optimizing coding and modulation techniques individually can lead to suboptimal results.

[10] Some Cellular Mobile Radio Service operators have chosen Code Division Multiple Access ("CDMA") because, among other things, it purportedly allows the same spectrum to be reused in adjacent beams of a sectorized antenna. This leads to greater spectral efficiency even though the modulation efficiency associated with each transmitter in each sector is less. The resulting increase in the total number of simultaneous messages that can be sent through a single cell site also leads to a greater spreading of fixed costs over more subscriber units and, hence, a reduction in infrastructure costs per subscriber.

[11] To get an idea of the possible magnitude of the cost impact of arbitrarily chosen spectral efficiency and related standards, consider the proposed construction requirement contained in para. 2 of the Notice for incumbent 39 GHz band licensees of rectangular service areas. This would require that licensees construct approximately one operating link per ten square miles for each licensed channel block within eighteen months from the adoption of a Report and Order in the proceeding.

IV. Lessons Learned from the DEMS/DTS Technical Rules

In Section II it was concluded that, except for the necessity to establish technical rules to protect other radio systems/services, there is no need for the Commission to establish minimum standards of spectral efficiency or requirements for frequency tolerance, emission masks, adjacent channel interference, or antenna characteristics in the 37.0 - 40.0 GHz band. In Section III, it was concluded that any specifying of such standards and requirements could seriously distort technology choices and raise costs unnecessarily. A review of the experience with the failed DEMS/DTS service -- a service with many characteristics in common with systems/services proposed for the new band -- demonstrates that these are not unwarranted concerns.

A. Background and History of DEMS/DTS

In November, 1978, Xerox Corporation filed a petition for rulemaking with the Commission requesting the allocation of spectrum from 10.55 to 10.68 GHz and adoption of technical and operating rules for a new, radio-based electronic message service. As envisioned by Xerox, the new service would support computer data transmissions, facsimile communications, and teleconferencing.

Based upon today's equipment costs, we estimate that the installed cost of a single digital microwave link in this frequency range would be approximately $20,000. Assuming an area of just 100,000 square miles (which represents less than 3 percent of the area of the United States), this link density requirement would cost licensees approximately ***200 million dollars***. If all fourteen channel blocks in the 39 GHz band were licensed in this 100,000 square mile area, the Commission's proposed construction requirement would impose a total cost of about ***2.8 billion dollars*** on licensees of these channel blocks. Even if the Commission's link density requirement can be justified, if other unnecessary standards, such as a modulation efficiency standard of 1 bps/Hz, imposed only a 10 percent cost penalty on the cost of the installed and operating links, licensees would be spending ***280 million dollars*** unnecessarily.

Direct network operating and human resource costs would add substantially to the above installed costs of the microwave links over the 18 month build-out period.

Additionally, these figures do not include any *extra* links (See Notice, para. 2) that could be required to be added to each channel--over and above the minimum link density requirement of approximately 1 link per 10 square miles--before any links can be added to a new channel and be counted in the per-channel link density requirement. If we interpret this requirement correctly, i.e. that as much frequency reuse as possible must be used with each channel before using another channel, this requirement could easily increase the above figures by many fold since substantial frequency reuse will be possible in this band, even though at least some of these links can be expected to cost substantially more than would links where frequency reuse intensity levels are lower.

In April, 1981, the Commission adopted a First Report and Order that allocated the requested spectrum and established rules for a Digital Electronic Message Service ("DEMS") that was similar in concept to that envisioned by Xerox in its petition. In the action, the Commission created a complicated channel plan in 130 MHz of spectrum between 10.55 and 10.68 GHz. Of the 130 MHz, 100 MHz was allocated for point-to-point Digital Termination Service ("DTS") technology and 30 MHz was allocated for point-to-point links to interconnect DTS nodal sites. The 100 MHz for DTS was, in turn, divided into seven 5 MHz channel pairs (70 MHz total) and six 2.5 MHz channel pairs (30 MHz total).

The Commission also adopted technical rules for DEMS. It required a 1 bit per second per hertz spectral efficiency standard, even though Xerox originally requested a more relaxed specification and despite the recognition that this specification "addresses only one facet of the spectral efficiency of a system and may be misleading."[12] It imposed a 0.5 watt output power limit and frequency stability requirements of 0.0001% for nodal stations and 0.0003% for user stations. It also adopted an emission mask that was "more stringent than the standard presently in the Rules."[13]

On reconsideration, the first of numerous technical rule changes was adopted. The changes included replacing the output power limit with a power density (watts per kilohertz of bandwidth) limit. In subsequent decisions, the Commission allocated additional spectrum and adopted technical rules for DEMS/DTS at 18 GHz as well as made a variety of changes in the technical rules in response to petitions from equipment manufacturers seeking ways to reduce equipment costs.

B. DEMS/DTS Licensing Activity

As soon as the DEMS/DTS allocation became effective, numerous parties filed license applications with the Commission. Among those entities that were granted DEMS licenses in 1982 and 1983 were National Microwave Interconnect Company (28 cities), Federal Express Corporation (15 cities), Digital Termination Service, Inc. (79 cities), Contemporary Communications Corporation (47 cities) and others. Consequently, DEMS became one of the first services where licenses were awarded by lottery after the Communications Amendment Act of 1982 gave the agency lottery authority.

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[12] In the Matter of Amendment to Parts 2, 21, 87 and 90 of the Commission's Rules to Allocate Spectrum for the Use of Radio in Digital Termination Systems, 86 FCC 2d 360, 378 (1981).

[13] 86 FCC 2d at 382 (citation omitted).